AD-A195 199 UNMANNED AIR VEHICLES - REAL TIME INTELLIGENCE WITHOUT THE RISK(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J B MILLER MAR 88 1/1

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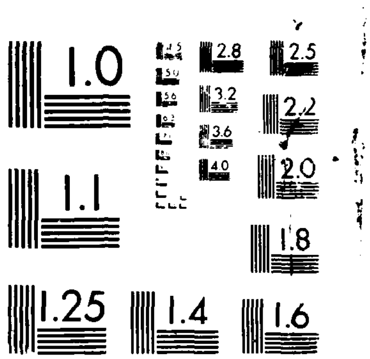

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

UNMANNED AIR VEHICLES -

REAL TIME INTELLIGENCE

WITHOUT THE RISK

by

James Bryan Miller

March 1988

Thesis Advisor: Thomas B. Grassey

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REPORT DOCUMENTATION PAGE

A1 95 199

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code)	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Monterey, CA 93943	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

UNMANNED AIR VEHICLES - REAL TIME INTELLIGENCE WITHOUT THE RISK

12 PERSONAL AUTHOR(S)
Miller, James B.

13a TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1988 March 18	77

16 SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Dept. of Defense or U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Unmanned Air Vehicle, UAV, Remotely Piloted Vehicle, RPV, Reconnaissance, Real-Time Intelligence, drones, [illegible]

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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This thesis asserts that UAVs should be used to supplement existing intelligence sensors, particularly in those cases where current sources are too ambiguous, slow, dangerous or take resources away from their primary duties. [illegible] intelligence; [illegible] intelligence;

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Thomas B. Grassey	22b TELEPHONE (Include Area Code) (408) 646-2521 22c OFFICE SYMBOL Code 56 GT

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete

☆ U.S. Government Printing Office: 1986—606-24.

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Unmanned Air Vehicles -
Real-Time Intelligence
Without the Risk

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN NATIONAL SECURITY AFFAIRS

from the

NAVAL POSTGRADUATE SCHOOL
March 1988

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ABSTRACT

Unmanned Air Vehicles (UAVs) are capable of supporting the officer in tactical command (OTC) by gathering intelligence in real- or near real-time. UAVs now under development will be able to collect high-resolution imagery, and thus provide the OTC with the option of gathering tactical intelligence without using manned reconnaissance platforms.

This thesis asserts that UAVs should be used to supplement existing intelligence sensors, particularly in those cases where current sources are too ambiguous, slow, dangerous or take resources away from their primary duties.

TABLE OF CONTENTS

Acknowledgment

I would like to thank my wife, Bernadette, for helping me with this thesis and for being so patient and understanding.

I would also like to acknowledge my thesis advisor, Professor Tom Grassey, and my second reader, Professor Rick Howard, for their commendable efforts in helping me write this thesis. Even though Professor Howard is with the Department of Aeronautics, the team work on the part of all concerned made the project run smoothly.

I. INTRODUCTION

> "There is no question in my mind that unmanned vehicles will play an increasingly important role...."
>
> Dr. Edward Teller (1982, 73)

There are gaps in the intelligence network that can be partly filled by unmanned air vehicles (UAVs). It is now possible to develop UAVs that can operate at sea, collect high-resolution imagery, and data-link that intelligence to the officer in tactical command (OTC) in real-time. This thesis will show that such UAVs are needed, that they are plausible, and in high threat areas, their use would be cost effective.

A. THE NEED FOR UAVs

Today, long range, highly accurate weapons are already in the inventory and more advanced-technology weapons are planned. But with the capability to conduct strikes over long ranges comes the need for highly reliable, timely intelligence. In order to maximize the capabilities of long range cruise missiles, precise classification, targeting and battle damage assessment (BDA) are needed--accurate weapons are of little value unless the commander knows where the enemy is. UAVs capable of relaying imagery intelligence

(IMINT) in real-time would improve the OTC's intelligence network.

1. UAVs to Supplement National IMINT Assets

In time of war, national imagery assets almost certainly will be overburdened with tasking. The enemy undoubtedly will put great emphasis on disrupting and interdicting the handful of intelligence assets and their associated command, control, communication, and intelligence (C^3I) systems. The tactical UAVs now under development will place under the command of the OTC the means of gathering high-resolution imagery without relying on nationally tasked sensors, or risking a manned reconnaissance aircraft. It would seem prudent for the U.S. Navy to equip the fleet with an intelligence asset to fill in the gaps that may exist in wartime.

2. UAVs in a War-At-Sea Scenario

In the heat of battle, the commander must be able to assess his adversary's strengths and weaknesses. Intelligence must be quick, accurate and unambiguous. Existing organic support aircraft (especially helicopters) are becoming increasingly vulnerable to enemy air defenses, and are unable to provide real-time imagery intelligence.

In cases where rules of engagement are restrictive, precise real-time classification, targeting, and BDA would be extremely valuable, especially in high traffic areas such

as the Mediterranean, Persian Gulf, and sea lanes around the world. (U.S. Navy 1987, 1)

3. Using UAVs To Conserve Aircraft

In a general war UAVs would free tactical aircraft for other missions and allow them to avoid the most dangerous reconnaissance missions. A major war may be fought with only those weapons on hand at the beginning of the conflict. If this is the case, it will be most important to avoid risking aircraft and crews unnecessarily. UAVs would give the commander the option of risking a lower cost platform, while using the more valuable manned aircraft on missions for which they are optimized. The Grumman F-14A was designed and purchased as an air superiority fighter, not as a reconnaissance aircraft. Considering the anti-air threat, the most cost-effective employment of fighter aircraft would be in anti-air warfare (AAW), not reconnaissance.

When the Carrier Battle Group (CVBG) Commander orders a manned reconnaissance aircraft to reconnoiter enemy held territory, there is an unavoidable risk that the aircraft and crew will be lost. UAVs can help solve this. Unmanned air vehicles could provide high-resolution imagery, comparable in quality to that collected by nationally tasked assets or F-14As equipped with tactical aerial reconnaissance Pod system (TARPS), and free tactical aircraft from the dangerous reconnaissance missions.

4. The Prospects for Stealth Technology

Some argue that stealth (reconnaissance) aircraft will be invulnerable and therefore make UAVs unnecessary. It is likely that stealth aircraft will be extremely valuable, as well as costly, assets. Even if low-observable aircraft are virtually invulnerable to air defenses, it is anticipated that the optimal use of those limited assets will be in conducting strikes rather than collecting intelligence. If this is so, it will be necessary to employ them in the missions for which they are optimized.

UAVs were among the earliest platforms to incorporate stealth technology. According to project manager Robert R. Schwanhausser, the Ryan model 147A repeatedly eluded Air Defense Command radars and interceptors during its operational test and evaluation in 1962. This was accomplished by covering the 27 foot-long UAV with radar blankets to minimize the radar cross section. (Wagner 1982, 37)

More recently, cruise missiles such as the General Dynamics Advanced Cruise Missile (ACM) have incorporated stealth concepts. Cruise missiles are inherently small targets, so the engineering challenge of applying stealth technology is not as great as for larger aircraft. (Sweetman 1985b, 1259)

If stealth concepts can be applied to cruise missiles, then it would seem logical that today's low-observable technology could be applied to UAVs.

5. Using UAVs When Politics Are a Factor

In this era of "violent peace" the U.S. Navy is called upon to deploy forces to areas of conflict on short notice. Lebanon, Libya, Grenada and the Persian Gulf remind us that the Navy is directed to take military action but to avoid inflicting civilian casualties. When there is so much media attention focused on the military, OTCs should anticipate being required to carry out surgical strikes, but without suffering casualties or having any personnel captured. Under these circumstances UAVs would be an ideal platform for conducting pre- and post-strike reconnaissance.

One lesson learned in the strikes on Lebanon and Libya is that Third World nations are often armed with significant air defense systems. This, when coupled with the increasing unacceptability of having American aircrews captured and held in enemy hands, forces us to reconsider the aerial intelligence problem. (Harris 1987, 101) One sure way to avoid combat loss or capture of aircrew is to use unmanned vehicles. Equipped with the General Dynamics Advanced Tactical Air Reconnaissance System (ATARS) sensors now under development, UAVs could gather high-resolution imagery and thus preclude the need for F-14A TARPS overflights.

The political profile raised by the loss of a manned reconnaissance aircraft is much higher than it would be for a downed UAV. The manned reconnaissance aircraft draws

unwanted publicity--the capture of Francis Gary Powers in May 1960 gained worldwide media exposure and caused the cancellation of further Lockheed U-2 flights over the U.S.S.R. In April 1965, the Peoples' Republic of China put three U.S. Ryan model 147B photo-reconnaissance UAVs (a variant of the BQM-34 Firebee) on display in Peking. In contrast to the U-2 incident, the U.S. was able to simply ignore the incident. The Chinese could claim whatever they wanted, but they did not have a captured American "spy pilot" as evidence. They did have the aircraft and its nameplates, but those items received nowhere near the amount of public attention as would an American pilot in prison. (Wagner 1982, 78)

6. Using UAVs to Save Lives

Over 5,000 Americans lost their lives in the Vietnam War because their aircraft were shot down or crashed due to malfunctions. Among the most dangerous missions were the reconnaissance flights. Additionally, 90% of the Americans who became prisoners of war were downed pilots or crewmen. Considering the number of crewmen lost, the use of RPVs looks even better. During the conflict in Southeast Asia, RPVs flew more than 3,000 missions over North Vietnam, China, Laos and elsewhere, with an attrition rate of less than 10%. (Schemmer 1982)

Because of these figures, many reconnaissance pilots became firm believers in RPVs. To evaluate the

effectiveness of North Vietnam's newly installed SA-2 Guidelines, the Air Force scheduled a dual U-2/RPV mission. The U-2 pilot witnessed the SA-2 consume the drone. This ended the U-2/RPV rivalry: the reconnaissance pilot simply said, "From now on, you guys can have that mission." (Wagner 1982, 99)

B. PLAUSABILITY OF UAVs

After the Vietnam War, the U.S. military reduced its RPV programs in favor of manned aircraft, saying that the RPVs did not perform as well as manned aircraft. The navigational accuracy of the Ryan model 147 (AQM-34) UAVs was limited to one nautical mile per hour of flight time by the Litton inertial navigation system. (Wagner 1982, 21) This inaccuracy resulted in difficulties in reconstructing the missions to correlate the intelligence gathered and the ground track. Israel, however, aggressively pursued its UAV programs.

The Israeli investment in UAVs was rewarded in June 1982, during the invasion of Lebanon. The relatively inexpensive and simple Tadrial Mastiff and Israel Aircraft Industries (IAI) Scouts were successfully employed in the Bekaa Valley. The UAVs, equipped with TV cameras and real-time data-links, were used to locate Syrian SAM sites. With this information, Israeli aircraft fired anti-radiation missiles to destroy the SAM's radars. With the air defense sites blinded, strike aircraft were able to

conduct cleanup operations as the UAVs conducted battle damage assessment and monitored the movement of Syrian forces. (Gwynne 1987, 40)

Reconnaissance UAVs have proven their value in combat in Vietnam and the Middle East, but should they be deployed with the fleet? The Navy believes so. It has issued a request for proposals for a medium range (MR) unmanned air vehicle capable of providing day and night reconnaissance and targeting to the OTC in real- or near-real time. The MR UAV will complement the Pioneer 1 short range unmanned air vehicle made by the AAI Corporation of Baltimore. The Pioneer has conducted day and night operations and demonstrated its television and Forward-Looking Infrared (FLIR) sensors.

C. COST EFFECTIVENESS OF UAVs

Any attempt in this thesis to quantify the cost effectiveness of UAVs is almost certain to leave out significant factors. The fact remains, however, that the cost of a UAV equipped with a sensor capable of relaying high-resolution imagery in real-time will be much lower than the cost of a tactical aircraft such as the F-14A TARPS--the stronger the enemy air defense system, the more cost effective the UAV when compared to the manned aircraft. Obviously, the higher the probability that the reconnaissance platform will be lost to enemy fire, or the

greater the cost difference between the UAV and a manned aircraft, the more attractive the UAV looks.

Considering that the cost of an MR UAV may be approximately one million dollars, and the cost of an F/A-18 (being considered for the reconnaissance role) is in excess of twenty-five million dollars, it is clear that it would take the loss of more than two dozen UAVs to begin to approximate the cost of a single manned F/A-18 reconnaissance aircraft. The figures are even more dramatic for the much more expensive F-14 (the F-14D being priced above seventy million dollars).

Even if the cost of a UAV system were just as expensive as a manned aircraft system, the fact that it gives the commander the option of not risking a manned aircraft, may justify the expense. Political costs--impossible to quantify--function as a significant factor. The commander may well be informed that the mission will be considered a failure if any crewmen are lost. If this were the case, the commander would find UAVs to be a most valuable addition to his list of options.

D. DEFINITION OF TERMS

There are differences in terminology and performance parameters for UAVs among U.S., NATO, and other European nations, so this paper will use the definitions of terms set forth by the U.S. Office of Naval Research.

The term "unmanned air vehicle" may be subdivided into three categories: pilotless target aircraft (PTA) more commonly referred to as "target drones;" preprogrammed/autonomous air vehicles which do not require midcourse guidance; and remotely piloted vehicles (RPVs) which do require commands from a ground or air controller (Figure 1). An RPV may offer a preprogrammed mode, but has the capability of being controlled in-flight. RPVs may be further subdivided by type: fixed wing, rotary wing, vertical/short take-off and landing (V/STOL), autogyro, and lighter than air.

UAV--Unmanned Air Vehicle

1. PTA--Pilotless Target Aircraft
2. Preprogrammed/Autonomous Air Vehicle
3. RPV--Remotely Piloted Aircraft (Airborne)
   a. Fixed Wing RPV
   b. Rotary Wing RPV
   c. V/STOL--Vertical/Short Take-off and Landing RPV
   d. Autogyro RPV
   e. LTA--Lighter Than Air RPV

Figure 1. Categories of UAVs

UAVs also may be described according to their operating range. Those capable of ranges less than 100 nautical miles (NM) are characterized as being short range; medium range is defined as 100 to 300 NM; long range is beyond 300 NM (Figure 2). (Coburn 1986, D-2)

RANGE -

SHORT < 100 NM
MEDIUM 100 - 300 NM
LONG > 300 NM

Figure 2. Definition of UAV Range

UAVs operating at speeds between 50 and 150 knots are defined as being capable of low speed; those with maximum speeds of between 150 and 350 knots are capable of medium speed; high speed is defined as greater than 350 knots (Figure 3). (Coburn 1986, D-2)

SPEED -

LOW 50 - 150 KNOTS
MEDIUM 150 - 350 KNOTS
HIGH > 350 KNOTS

Figure 3. Definition of UAV Speed

Endurance of less than two hours is defined as being short; between two and five hours is medium; and UAVs capable of more than five hours are defined as long endurance (Figure 4). (Coburn 1986, D-2)

ENDURANCE -

SHORT < 2 HOURS
MEDIUM 2 - 5 HOURS
LONG > 5 HOURS

Figure 4. Definition of UAV Endurance

II. BACKGROUND

"In January, 1984, the fleet commander off Lebanon ... made it very clear that he saw an immediate need for RPVs."

Rear Admiral Ronald Marryott
Office of the Deputy CNO for
Plans, Policy and Operations
(Klass 1984, 44)

The U.S. Navy has been investigating the feasibility of using unmanned aircraft to avoid risking the pilot since Elmer Sperry, inventor of the gyroscope, proposed an unmanned airplane designed to fly a pre-set heading and dive at a preset range. Navy Lieutenant T.S. Wilkinson, representing the Bureau of Ordnance, observed the test of the unpiloted airplane on September 12, 1916. Although Wilkinson was impressed, he did not consider the weapon accurate enough to attack ships. Navy interest continued, however, and on October 17, 1918 a modified N-9 training plane made a successful unmanned flight. It flew a preset heading until its fuel was exhausted, at approximately seventy miles range. The unmanned aircraft's gyro maintained its course within two degrees of the planned track. Interest in the project dwindled as the Navy discovered that the pilotless plane could not be set to fly at altitudes low enough to attack ships, nor was it accurate enough. (Friedman 1985, 215)

Development of RPVs was minimal in the inter-war years, except in the area of target drones. Nevertheless, in July 1940, with World War II on the horizon, the Navy drone squadron (VJ-3) demonstrated that an unmanned air vehicle could be controlled from a distance to attack a target. By August 1941 the control range had been increased to six miles, using a television camera aboard the RPV. The television had the advantage that the control pilots did not have to keep the RPV in visual contact. Under project "Fox," on April 9, 1942, a television-guided RPV made a successful test torpedo run against the destroyer USS Aaron Ward (DD 483). Later that month, a television-guided BG-1 RPV dove into a target. Tests of the remotely piloted vehicles were successful enough for the Vice Chief of Naval Operations, Admiral F.J. Horne, to ask for 3000 drones. Nine RPV squadrons were formed by January 1944, but by that time, carrier aircraft were winning the air war, and the perceived need for unconventional attack aircraft diminished. (Friedman 1985, 216)

Before the program was eliminated, RPVs were used in combat. In June 1944, RPVs were used to attack the beached Japanese freighter Yamazuki Maru, at Cape Esperance. And on September 17, 1944 a plastic TDR-1 RPV, made by Interstate, was used to attack a beached antiaircraft ship at Khili, South Bougainville. The attack was reportedly quite

successful--the RPV's small size made it a difficult target for anti-aircraft gunners. (Friedman 1985, 216)

In 1944, the same technology was applied to convert worn out B-17 Flying Fortress and Army Air Force/Navy B-24/PB4Y Liberator bombers into unmanned air vehicles. They were loaded with explosives, their pilots parachuted to safety once the plane was airborne, and a trailing plane, usually a B-34/PV-1 Ventura, guided the plane to the target. This program led to the successful attack on Heligoland on September 3, 1944. (Fitzsimons 1979, 2242)

During the Korean War, remotely controlled F6F Hellcats, each armed with a 2000 pound bomb, were catapulted from the USS Boxer (CV 21) on one-way missions against heavily defended targets. The RPVs were controlled from Douglas AD-2D Skyraiders, with television used for terminal guidance. The Hellcat RPVs suffered from several drawbacks: they required 30 minutes of servicing before takeoff, during which time the right wing was required to be unfolded so that the television camera could be installed; the ship was required to maintain a steady course to permit the RPV's gyro-stabilizer to be checked; and the RPV was considered vulnerable to groundfire because its control system was relatively easy to disable. (Friedman 1985, 227)

A. NEW INTEREST IN RPVs--RECONNAISSANCE

Strike missions are not the only flights which endanger crews. Reconnaissance flights, even in peacetime, can also

be extremely hazardous. On May 1, 1960, Francis Gary Powers' U-2 was shot down over the U.S.S.R. This, along with the loss of Major Rudolph Anderson, Jr. when his U-2 was shot down over Cuba during the missile crisis of October 1962, stimulated the U.S. government to initiate an urgent program to develop RPVs capable of supplementing the limited number of manned reconnaissance aircraft. (GAO 1981, 1)

Within ninety days of the loss of the U-2 over Cuba, the Ryan Aeronautical Company produced its first reconnaissance RPV, the model 147, based on the Firebee target drone. During their operational test and evaluation, staged from McDill Air Force Base (AFB) near Tampa, the model 147s were able to make repeated penetrations of the U.S. air defense net without being detected. (Wagner 1982, 35-41)

B. RPVs OVER VIETNAM AND CHINA

RPVs were used extensively between 1964 and 1975 to collect imagery and electronic intelligence, conduct electronic countermeasures, fly decoy missions and even drop propaganda leaflets. (Wagner 1982, 213)

The vast majority of reconnaissance missions were carried out by the highly classified family of Ryan model 147s (AQM-34). The 147s, based out of Kadena Air Base on Okinawa, were used extensively to gather intelligence over the People's Republic of China, starting with the "Blue

Springs" program in 1964 and abruptly ending in 1971 as a consequence of President Nixon's diplomatic overtures to China (Reed 1979, 75). These missions came to light in November 1964, when the People's Republic of China claimed it had shot down an unmanned American "high-altitude reconnaissance military plane" over central China. Although the Chinese did have the aircraft, the U.S. did not acknowledge responsibility for the vehicle and the incident did not draw the same public attention as did the Gary Powers capture. (Wagner 1982, 77-78)

The vast majority of the operational RPV flights in the Far East were carried out by the 100th Strategic Reconnaissance Wing (SRW), operating out of Bien Hoa Air Force Base, South Vietnam. The General Accounting Office reports:

> Flying over 3,000 sorties, with an attrition rate of less than 10 percent, [RPVs] were primarily used for photographing targets for air attack, recording damage after bombing, and even discovering unsuspected key targets like the huge North Vietnamese fuel storage areas in a suburb of Hanoi.
>
> The RPVs flew over North Vietnam at both high and low levels, relying on their speed and small size to elude the heavy and effective North Vietnamese defenses. (GAO 1981, 1-2)

In April 1972, Dr. John Lucas, Under Secretary of the Air Force, remarked on the RPVs used in Vietnam: "The successful development of drones for aerial photography had added significantly to our reconnaissance and surveillance capabilty." (Wagner 1982, 208)

General John C. Meyer, Commander of the Strategic Air Command was quoted in November 1972:

> Drones...have been doing low altitude Reconnaissance flying over heavily defended areas of North Vietnam.
>
> The disadvantage of using drones this way is that we lose a lot of them. The loss rate is higher but we are willing to risk more of them, and they save lives. (Wagner 1982, 208)

Another advantage of using RPVs to conduct reconnaissance in Vietnam was that they could fly at low altitude, under the weather, to photograph their targets. During December 1972, the Northeast monsoon usually resulted in ceilings of 2,000 to 3,000 feet. Admiral Thomas H. Moorer, Chairman of the Joint Chiefs of Staff, briefed Congress on the results of the December bombings of Hanoi. When questioned about the source of the photographs, Moorer answered:

> We are using drones.... That was the reason I showed you more than one picture of the same target because the drones are so close to it that they cannot get all the target in one photograph. (Wagner 1982, 201-202)

The 100th SRW launched and controlled the RPVs from Lockheed DC-130 Hercules aircraft, and adapted Sikorsky CH-3 helicopters to recover the vehicles in mid-air, as they decended by parachute (see chapter III). The Mid-air Retrieval System (MARS) was not very successful at first--only half of the attempts were accomplished. However, once the techniques were perfected the success rate rose sharply. (Reed 1979, 63) There were 2745 MARS attempts in Southeast

Asia, of which 2655 were successful, which translates to a 96.7% success rate (Wagner 1982, 109).

RPVs did not gain a good reputation for themselves in Southeast Asia. They required relatively complex operating procedures--launch from a DC-130 and MARS recovery. The RPV's navigation system was not very accurate, so it was often difficult during post-flight analysis to correlate the intelligence gathered with the path actually flown. The attrition rate was high, and this made the program relatively expensive. Finally, it was perceived that required servicing for the RPVs took too long. (Reed 1979, 62)

The bad reputation was not entirely justified. The U.S. pressed the Ryan RPVs into service without adequate testing. Many of the vehicles were lost in accidents which could have been avoided had the normal test and evaluation proceedures been followed. (Reed 1979, 62-69) An RPV exhausted its fuel during a 1962 test, because the engineers forgot that a jet uses considerably more fuel at low altitude than it does at high altitude (Wagner 1982, 37). The secrecy surrounding the RPV programs resulted in additional mistakes because the engineers were not cleared to view the results of the reconnaissance missions. In 1965, there were complaints about the quality of the photography provided by RPVs; further investigation revealed

that the Air Force photography lab simply had processed the film improperly (Wagner 1982, 83).

C. DASH

The Navy started development of the Drone Anti-submarine Helicopter (DASH) in 1958 as a method of transporting anti-submarine torpedoes or nuclear depth bombs to their target. The program suffered from many operational difficulties, and of the 746 DASHs built, over half were lost at sea. One of the reasons was that the operator lacked any feedback from the helicopter. Another was that DASH was a Bureau of Aeronautics project, but it operated in a Bureau of Ships enviornment where it lacked a constituency. According to Norman Friedman, "...reportedly, some captains preferred to order their drones flown into the sea rather than operate them." (Friedman 1985, 129)
In contrast to the U.S. experience, the Japanese Navy purchased seventeen DASHs and did not lose any. The QH-50 helicopters also were operated over Vietnam in an effective gunfire spotting program, called "Snoopy DASH," made possible by installing a commercial television camera on the RPV. (Friedman 1985, 128-29)

D. ISRAELI USE OF RPVs

In the 1973 Arab-Israeli war, the Israelis showed that RPVs could be used effectively as decoys. Inexpensive, expendable drones excited the enemy air defense sites by

emitting electronic signatures similar to those of threat aircraft. The enemy fired their SAMs at the drones, and as the SAM sites were reloading, strike aircraft and Shrike anti-radiation missiles destroyed the sites' radars. (Wieand 1985, 6)

During the 1982 Israeli invasion of Lebanon, the Israelis modified this basic technique only slightly and destroyed a substantial portion of the Syrian air defense system. Tadrian Mastiff RPVs photographed Syrian missile sites in the Bekaa valley, and then used ECM equipment to stimulate the SAM's radar by producing the radar image of strike aircraft. ESM-equipped Israel Aircraft Industries' Scout RPVs relayed the location and characteristics of the signals to an EW-equipped Boeing 707. (Hooton 1984, 337) When it was time for the June 9th attack, a wave of air-launched decoys drew the first barrage of missiles. Almost immediately, 24 F-4 Phantoms fired ARMs at the radar and control vans. By the end of the first wave's attack, 17 out of 29 sites had been destroyed. This wave was quickly followed by 40 strike aircraft and further attacks on the SAM sites. (Interavia 1985, 4) The IAI Scout RPVs then conducted bomb damage assessment of the sites. (Sweetman 1985a, 1771)

Although Israel's successess with RPVs in the Bekaa Valley are significant, it must be remembered that the Israeli military was operating in a familiar area and had

the luxury of being able to spend three years planning the mission. The U.S. military almost certainly would not have such favorable conditions. We are forced to consider the possibility of operating any prospective RPV in a hostile EW environment, where the data-links could be jammed. (Gwynne 1987, 40)

E. RENEWED U.S. INTEREST IN RPVs

The Navy and Marine Corps interest in RPVs has been spurred by lessons learned in Lebanon in 1983, when U.S. forces were sent into Beruit as part of the multi-national force. According to Rear Admiral Ronald Marryott, Deputy CNO for Plans, Policy and Operations:

> We had to depend largely on F-14s for reconnaissance and bomb damage assessment of the USS New Jersey's 16 inch gunfire. Tactical prudence and foul weather often precluded timely use of F-14s to survey the results of bomb damage, especially in enemy defended areas. (Klass 1984, 44)

To remedy this weakness, the Secretary of the Navy, John Lehman, decided to acquire the Mastiff-3 and the Pioneer RPVs. Marryott cited the Israelis' "tremendous success" in using RPVs against Syrian forces "to gather real-time intelligence on SAM sites...for artillery spotting, forward area control and battlefield management." (Klass 1984, 44)

The main reason the Pioneer and Mastiff RPVs were selected by the Navy was because they could be delivered quickly. The Navy's original required operational

capability (ROC) statement was rewritten by Secretary Lehman in July 1985 to reflect his desire to attain minimum essential capability as soon as possible. (Sweetman 1985a, 1774)

The ROC was controversial. Losing manufacturers claimed it was tailored so that only the Israeli system would be in a position to win. Only one manufacturer, Pacific Aerosystems Inc., maker of the Heron 26, tried to compete, and it withdrew, leaving only AAI of Baltimore. (Dunn 1986, 35) But the Navy did receive an RPV in a timely manner--the contract was awarded in December 1985, and by December 1986 the Pioneer was operating from the USS Iowa (BB 61).

F. SOVIET RPVs IN THE MIDDLE EAST

Israel and the U.S. are not the only countries interested in RPVs for gathering reconnaissance. In early 1984, the first Soviet mini-RPV in service in Syria was observed. Designated the DR-3, it is configured with twin booms and swept wings, similar to the Israeli Scout and Mastiff and carries a fixed, non-stabilized television camera. Interavia (1985, 4) reports that a follow-on RPV, equipped with a stabilized, steerable camera has been developed.

Israeli Defense Forces have shot down at least two Soviet UR-1 unmanned reconnaissance vehicles. The UR-1 is an air-launched, high-altitude target drone that is also

capable of conducting reconnaissance. It may be equipped with either a television camera, electronic jammers or electronic intelligence payload. (Wrixon 1986, 689)

The U.S. seems to have learned a lesson from Israel: RPVs have their place in modern warfare. The U.S. Navy has taken a multi-track approach to put RPVs into service with the fleet: The short-range Pioneer has already conducted operations from the USS Iowa (BB 61); ten Northrop BQM-74C target drones have been purchased for use in the development of operational requirements for the proposed medium-range UAV ("Northrop" 1986, 123); there are plans to purchase medium-range reconnaissance UAVs and long-range, long-endurance UAVs.

G. SUMMARY OF OPERATIONAL RECONNAISSANCE UAVs

1. CL-89

Canadair's CL-89 (NATO designation AN/USD-501) is the UAV that has received the widest acceptance outside the United States. Nearly 600 CL-89s have been produced, and they are in service in the militaries of Canada, Italy, Germany and the United Kingdom. The French Army also has purchased the CL-89 for use intargeting for its Pluton tactical nuclear missiles. (Bulloch 1979, 336-37) The CL-89 is a reusable, fixed wing, turbojet-powered reconnaissance vehicle, equipped with an IR line-scanner/photo camera. The UAV is capable of 460 knots and a range of 75 NM ("International" 1987, 178).

The disadvantages of the CL-89 include its short range, restrictions on the number of waypoints, the fact that only one sensor can be carried at a time, and that the imagery cannot be down-linked; film must be retrieved and processed. (Wanstall 1986, 387) In addition to the lack of timeliness, if the vehicle is lost while returning from the mission, the intelligence is lost.

2. CL-289

Canadair is developing the CL-289, NATO designation AN/USD-502, in conjunction with Dornier of Germany and SAT of France. Like its predecessor, the CL-89, the CL-289 is rocket-launched and parachute recovered, but it will have approximately twice the range. ("International" 1987, 178)

3. Epervier

Belgium's MBLE (Manufacture Belge de Lampes et de Materiel Electronique) produces the Epervier, a short-range, turbo-jet powered UAV that offers real-time data transmission. The Epervier can fly at speeds in excess of 350 knots and also is capable of either externally guided or pre-programmed flight. The Epervier was built to meet NATO requirements, but lost out to the CL-89 and so was purchased by the Belgian Army. (Bullock 1979, 337)

4. Mastiff and Scout

The Mastiff was designed by Tadrian Israeli Electronic Industries, Ltd., which has now merged with IAI (which designed the Scout) to form Mazlat (the name "Mazlat"

corresponds to the Hebrew acronym for RPV). The design philosophy at Mazlat is that ground equipment is the most important element in the system. The RPV uses different payloads for specific missions, but uses common launchers and ground stations. (Sweetman 1985, 1772-73)

Both the Mastiff and Scout are capable of being launched by catapult to fly at 90-100 knots on a route which can be pre-programmed or controlled from the ground control station. Both RPVs are capable of over seven hours flight endurance. Between the two vehicles, the RPVs can accommodate the following payloads: television, photo camera, FLIR, laser designator or electronic warfare payload. ("International" 1987, 178)

5. Mirach-20

Italy's Meteor Aircraft & Electronics produces the Mirach-20, a mini-RPV equipped a television camera or FLIR, for real-time target acquisition, designation, and surveillance; an over-the-horizon acquisition radar which has a range of 50 NM; or a laser designator. The Mirach-20 is capable of 120 knots and six hours endurance ("International" 1987, 178) and may be directed from the ground or use pre-programmed automatic Omega/VLF navigation. The "Parrot" version of the Mirach-20 is fully pre-programmed and therefore does not require a ground control station. "Parrot" is used for communications relay, jamming or electronic support measures (ESM) mission.

A civilian version, "Gabbiano," is used to drop liferafts at sea for rescue operations. (Jane's 1987, 826)

6. Mirach-100

The Mirach-100 is produced in both target and reconnaissance versions. More than 150 "100s" have been manufactured in Italy and under licence in Argentina by Quimar under the name MQ-2 Bigua. Also, reconnaissance versions of the Mirach-100s have been exported to Iraq and Libya. The export version is air launched from Agusta A109 and Aerospatiale Dauphin helicopters (Lenorovitz 1987, 53). The UAV has an endurance of one hour, and a maximum speed of 450 knots ("International" 1987, 178).

The reconnaissance version of the "100" is fully pre-programmed, and offers low-light television, panoramic camera, IR line scanner or electronic intelligence payloads (Wanstall 1986, 390) as well as a wide-band transmitter with jam-resistant data-link ("Mirach" 1987, 97).

The UAV's navigation system, "Sirah," enables the vehicle to loiter over a selected area and conduct surveillance. The Mirach-100 is also reported to have potential applications as a tatical cruise missile (Jane's 1987, 826)--its payload is estimated to be approximately 88 pounds (Coburn 1986, A-2).

7. Stabileye

The Stabileye RPV, developed by British Aerospace's Naval Weapons Division, is powered by a pusher-type

propeller and is capable of speeds up to 129 knots. Stabileye can remain aloft four hours and provide real-time imagery from either an IR line scanner or television camera. The RPV also has the capability to gather photographic (film) intelligence. The most unusual aspect of the Stabileye system is the ability of the groundcontrol station to control three of the RPVs in flight at the same time. (Coburn 1985, 1) Stabileye is also capable of serving as a platform for flight testing payloads (Dunn 1986, 40).

8. Pioneer

The Pioneer RPV is currently in use by the Navy. To date it has demonstrated at-sea, daylight launch and recovery, and, using its television camera, spotting for naval gunfire. Although Pioneer has conducted operations at sea, the system is still being perfected and should be fully operational by 1989. (Fisher 1987)

9. Skyeye

Developmental Sciences' R4E series of RPVs are operational in the Thai & U.S. armies. The R4E series can perform day and night real-time reconnaissance, weather observation, gunfire and close air support, laser designation, BDA and electronic warfare. (Jane's 1987, 850)

The U.S. Army's R4E-40 is also capable of being equipped with a nose-mounted television in conjunction with underwing rocket launchers. Underwing pods may also

accommodate extra fuel, chaff, leaflets, flares or communications jammers. (Jane's 1987, 850)

According to Aviation Week & Space Technology, the R4E-40 has been used in Thailand and by the U.S. Army in Central America.

Developmental Sciences refers to the R4E as a versatile "truck" that does not require an expensive custom-made payload. It also claims that it can carry a 140 pound payload for eight hours. It has demonstrated a 9.3 hour endurance with a Texas Instruments AIR-360/3 FLIR payload weighing 90 pounds. ("Developmental Sciences Prepares Skyeye" 1986, 68-76)

III. SURVEY OF UAV TECHNOLOGY

Before military officers can be prepared to decide the proper role of UAVs, they must have an understanding of the associated technology. This chapter is intended for those who have not studied UAV technology. Those familiar with the trade-offs associated with UAVs will have less need to read this chapter.

Just as no single reconnaissance platform is optimal for all missions, there is no UAV that can meet the needs of all intelligence users. This chapter addresses the capabilities and limitations of different aspects of UAV technology.

A. UAV AIRFRAME TECHNOLOGY

UAVs have been built in a variety of configurations: fixed wing, rotary wing, vertical/short take-off and landing (V/STOL), autogyro, and lighter-than-air (LTA). Each has advantages and disadvantages, which will be summarized briefly.

1. Fixed-Wing UAVs

Most of the UAVs under development or currently operational fall into the fixed-wing category. Fixed-wing designs have the relative advantages of high payload/airframe weight ratio, high speed, long range, lower

manufacturing cost, lower maintenance cost, and higher reliability and availability. (Coburn 1986, 5-6)

The main disadvantage of fixed-wing designs is that landing them aboard ship is difficult because of their relatively high landing speed. The methods most often used are: net recovery (used to land the Navy's Pioneer aboard battleships), and parachute recovery (such as the Mirach-20), which allows the vehicle to land in the water (Jane's 1987, 826). (See below for further discussion)

2. Rotory-Wing UAVs

Deployment of UAVs at sea would be simplified if complex launch and recovery gear were not required. Also, shipboard use would be more readily accepted if the vehicle did not approach the ship at high speed, which increases the chance that a mishap would damage the ship.

The chief advantage of Remotely Piloted Helicopters (RPHs) is that they are capable of taking off and landing vertically. Unmanned helicopters require relatively little deck space and launch or recovery equipment. For these reasons, unmanned helicopters are the UAV type most adaptable to shipboard use.

The flexibility of the helicopter is paid for, however, in decreased endurance and range. In general, fixed-wing aircraft have two to three times the range or endurance of an RPH. (Coburn 1986, 6) Remotely Piloted Helicopters would be capable of conducting short

range reconnaissance (less than 100 NM from the launch platform), but for longer range missions RPHs would not be the optimal platform because of their speed, endurance, and range limitations. The fastest RPH uncovered in this research was Aerodyne's CH-84, which evolved from the Navy's QH-50D DASH RPH. The CH-84 cruises at 135-140 knots and has a maxium speed of 150 knots--less than one third the maximum speed of the Navy's proposed (turbojet powered, fixed-wing) medium range UAV. ("Aerodyne" 1986, 108)

3. Vertical/Short Take-Off and Landing UAVs

Bell Helicopter Textron/Boeing Vertol is developing a tilt-rotor design, based on the Bell-Boeing V-22 Osprey. This configuration, called the "Pointer," would combine high speed and endurance with the capability of being able to take off and land like a helicopter. The design team estimates that the Pointer would have a dash speed of 160 knots and endurance of seven hours (at 70 knots). (Greeley 1987, 58)

4. Unmanned Autogyro

An autogyro is a rotorcraft which generates thrust with a pusher-type propeller and lift with a free-wheeling (unpowered) rotor. As with the helicopter, the autogyro is capable of very slow forward flight. Its main advantage as a UAV may be its ability, with the wind at the proper magnitude and direction, to remain airborne for very long

periods of time. A search of the literature revealed only one unmanned autogyro--the Vinten Vindicator, which has a maximum speed of 80 knots and a five hour endurance. (Coburn 1986, 6-7 & A-2)

5. Lighter-than-air UAVs

The idea of lighter-than-air UAVs has been explored in the past, and several U.S. designs have flown. The remotely-piloted blimp "Silent Joe I" was flown successfully on several occasions during the Vietnam war. This small (5500 cubic foot) blimp was capable of 15 knots, powered by dual three horsepower chainsaw engines. (Vittek 1974, 588-89)

Silent Joe II used the 150,000 cubic foot hull of the Goodyear blimp "Mayflower." Silent Joe II flew nine successful flights in 1968-69 to demonstrate the concept of large remotely-piloted blimps. (Vittek 1974, 589)

The Micro Blimp was a 2750 cubic foot, 37 foot long mini-blimp powered by a four horsepower engine. This program, carried out in the early 1970's, resulted in flights as long as ten hours, altitudes up to 5000 feet, and airspeeds as fast as 30 knots. Heading and pitch stability were maintained by an autopilot. (Vittek 1974, 589)

The advantages of a lighter-than-air UAV include: long endurance, safety (because of slow approach speeds at landing), less vibration (should result in better imagery),

quiet when loitering (requires little power), low IR signature when at low power, and the capability of slow flight for long endurance station-keeping.

The disadvantages include: slow maximum speed, vulnerability because of slow speed, the fact that lighter-than-air UAV is easier to see than smaller UAVs, restricted range due to its slow speed, the difficulties of handling a lighter-than-air vehicle on the surface in high wind, size (when inflated) and its impact on shipboard stowage and operations.

B. UAV PROPULSION TECHNOLOGY

1. Propellers and Internal Combustion Engines

The most common mode of propulsion for UAVs currently deployed or under development is the propeller driven by an internal combustion engine. This type of engine is popular with UAV designers because of its low price, high reliability, low development risk, and favorable fuel consumption.

The two-stroke, gasoline-powered engine is the most commonly used UAV engine. Its disadvantages include the high level of noise it generates and the volatility of its fuel. Gasoline presents a problem; U.S. Navy ships had eliminated gasoline because of the danger of explosion and fire. (Coburn 1986, 14) The Navy is working on an alternate fuel program to solve this problem. (Yencha 1987)

One solution to the fuel problem would be to convert a rotary engine to run on diesel fuel. Small rotary engines, such as would be used in UAVs, have a long history of success and have been run on a wide variety of fuels. The Curtiss-Wright Corporation's RC-2-90 rotary engine has been modified to run on diesel or JP fuels. Although this engine is water-cooled, a similar model was built as an aircraft engine. (Coburn 1986, 14-15)

2. <u>Turbojets</u>

The primary advantage of turbojets in UAVs is the high speed they offer. The trade-off for the high speed capability is the high fuel consumption and thus shorter endurance for a given quantity of fuel. This penalty may be worth paying, however, if the UAV is conducting reconnaissance against a distant target. In order to collect intelligence when time is an overriding factor, medium range (100-300 NM) UAVs must be capable of high speeds.

All of the UAVs capable of high speed flight are turbojet-powered. A partial list would include the Mirach-100, the Epervier, the CL-89 and the CL-289. All of these are capable of maximum speeds in excess of 350 knots. The Navy's proposed medium range UAV will undoubtedly be turbojet-powered in order to meet the service's operational requirement of being able to image an enemy airfield 350 NM from the launch point and have that imagery available to the

tactical commander within two hours of launch (Greeley 1986, 48).

3. Coaxial Rotors

The vast majority of rotary wing UAVs have coaxial, counter-rotating rotors. This configuration does not require a tail rotor, making it safer for shipboard operations. Current coaxial rotor RPH designs include the Aerodyne CH-84, the Canadair CL-227, and ML Aviation Sprite.

4. Electric Motor

Electric motors are quiet, inexpensive, require little maintenance, and do not use volatile fuel. These advantages would seem to make electric motors the ideal power source for UAVs. The limiting factor is that they depend on batteries which are relatively heavy for the amount of power they provide. Battery-powered UAVs are ideal for missions where slow speed or short range are acceptable limitations. One UAV that uses an electric motor for propulsion is the British Aerospace Plover, which serves as a decoy. (Coburn 1986, A-3)

C. UAV GUIDANCE AND CONTROL SYSTEMS

The type of guidance and control system employed depends on the mission the UAV is designed to accomplish. If the vehicle is required to fly 200 NM from a ship, collect photographic intelligence at low altitude, and return to the ship, the guidance and control system will be

much more complex than if the mission does not require the UAV to go beyond the radar horizon.

UAVs can be flown with an autonomous guidance and control system; they can be designed to fly a pre-programmed flight profile; or they may be flown under the direct control of a surface or airborne agent.

1. Autonomous Guidance and Control

An autonomous guidance system provides a true "launch and forget" capability, like that of the Tomahawk cruise missile. This is attractive because it provides very accurate navigation without requiring the launch platform to emit electronic signals to control the UAV. Unfortunately, such an autonomous UAV requires a very expensive guidance system; also, an autonomous system often is relatively heavy, which results in the need to sacrifice either fuel or sensor payload. (Coburn 1986, 18-19)

2. Pre-Programmed Flight Profile

Pre-programmed flight profile with data link update is the system type most commonly used today. Examples are too numerous to list, but U.S. systems include the AAI Pioneer, the Northrop NV-144, and the Teledyne Ryan MQM-34M. ("U.S. RPVs" 1987, 176-77) While a UAV with this type of guidance and control system is capable of a "launch and forget" mission, most systems utilize data link updates to increase the navigational accuracy. Without updates, navigational errors of two to five percent of range can be expected. (Coburn 1986, 19)

Most pre-programmed UAVs navigate by dead reckoning, using inputs from airspeed, heading and altitude sensors. The controller commonly tracks the vehicle with radar, often with the use of an onboard beacon, data linking control signals to keep the UAV flying the desired track or to alter the track inflight.

This system, being simpler than an autonomous control system, requires less expensive or lighter navigation equipment. The main disadvantage is that radio silence cannot be maintained by the controlling unit. As a corollary, the data link can be made secure and jam resistant, but the trade-offs include cost, weight, and complexity. There is a distinct possibility that UAVs would be used in a high threat (electronic warfare) environment, and if so, a jam resistant link would be required.

3. Direct Control

Unmanned Air Vehicles usually have the capability to be directed from a control station on the ground, aboard ship, or in an aircraft. This system of guidance is quite accurate, and does not require expensive onboard navigation systems. The disadvantages are that radio silence is not possible, and for most systems the vehicle must be within line-of-sight of the control station or relay unit. (Coburn 1986, 19)

D. LAUNCH AND RECOVERY SYSTEMS

For UAVs to be widely accepted, the problems of launch and recovery need to be solved. Launching and recovering conventional aircraft aboard a carrier is a complex and dangerous evolution, more so than on land. Operating UAVs at sea also is more difficult than on land.

The problem of launch and recovery of small and slow UAVs at sea, including rotary-wing UAVs such as DASH, has been challenging. However, as the capabilities of UAVs (range, size, and speed) increase, the launch and recovery problems generally become greater. This section will deal only with the problems associated with launch and recovery of UAVs at sea.

1. Launch Systems

Launch of UAVs can be accomplished by a variety of methods, including: rocket, conventional, VTOL, flywheel, pneumatic, hydraulic, and elastic cord.

a. Rocket

The most common method used to launch sea-based UAVs is via rail and with rocket assist. This method has been successfully employed to launch the Pioneer RPVs from the battleship USS Iowa (BB 61). (Fisher 1987) Under this system the rocket booster falls away shortly after launch. Rocket launch from ships has the advantage that complex and expensive equipment is minimized. Additional advantages are that rocket launch is very reliable and the time needed to

set up the launcher for the next launch is relatively short. Disadvantages include the necessity for pyrotechnic storage, corrosive products of combustion, and logistics. (Coburn 1986, 22) This method shows great potential for launching medium range UAVs that would otherwise require large and complex launch systems.

b. Conventional

Although conventional take-off and landing of fixed-wing UAVs at sea is not impossible, almost certainly it would be impractical because of the need for a large flat deck. The only ships equipped for this operation are aircraft carriers and amphibious helicopter carriers (LHA, LPH, LHD). The deck space on these ships is more efficiently employed by conventional aircraft. UAV conventional take-off and landing operations, although technically possible, would not appear to be the optimal use of the large deck ships. Also, there are concerns that conventional aircraft on the flight deck would be endangered by UAV operations.

c. VTOL

The method of launch and recovery that offers the greatest flexibility in the deployment of UAVs at sea is vertical take-off and landing. VTOL vehicles can be designed to operate from any ship capable of helicopter operations. This option is worthy of consideration for

short range UAVs (those with ranges out to 100 NM) or when their relatively slow speeds are not a hindrance.

d. Pneumatic

Pneumatic launchers use compressed gas to power a shuttle along a rail to accelerate the vehicle. The principal drawback is the jerk associated with launch. The shorter the rail, the greater the jerk: a 660 lb vehicle, while accelerating to 68 kts, will experience up to 50 g's if the launcher is five feet long. (The amount of jerk declines as the length increases: 20 g's with 16 foot rail, 10 g's with 26 feet.) Most UAVs can withstand 15-20 g's at launch, but sensitive intelligence payloads may not be able to withstand the g forces associated with pneumatic launch. (Coburn 1986, 22-23)

e. Hydraulic

Hydraulic launchers are similar to pneumatic systems, but use hydraulic fluid to control the jerk at launch initiation. The disadvantages are that they are relatively large and complex. (Coburn 1986, 23)

f. Flywheel

A flywheel may be used to provide the energy to propel the vehicle down the launch rail. The advantages are: low cost, less jerk from acceleration, constant and reliable launch velocity, and freedom from ordnance hazards. The drawback of deploying flywheel launchers aboard ships is their relatively large size and complexity. (Coburn 1986, 22)

g. Elastic Cord

An elastic cord can be used to launch very small UAVs. Bungees offer the obvious advantages of low cost and simplicity. Cold weather operations, however, require the cord, which is two inches in diameter and 20 feet long, to be heated to above 32°F. The British regularly use this method at sea to launch the Banshee and Spectre unmanned air vehicles which weigh approximately 134 pounds. (Coburn 1986, 23)

2. Recovery Systems

The alternatives to recovering UAVs at sea are to recover them ashore or develop expendable vehicles. Land recovery is being proposed for the long-endurance UAV proposed for the U.S. Navy, but this method is not plausible for short and medium range UAVs. Expendable UAVs would eliminate the difficulties of recovery, but the cost of each vehicle would of necessity be much lower than UAVs capable of multiple flights. The result probably would be that high resolution imaging systems, secure data links, and accurate navigation systems would not be affordable in the expendable UAVs.

Recovery of UAVs at sea can be accomplished by a number of methods, but none of them is without serious drawbacks. The methods that this section will analyze are: net, parachute, parafoil, VTOL, Helicopter Midair Recovery (MARS), and conventional.

a. Net

U.S. Navy Pioneers and Marine Corp Mastiffs have been recovered at sea by flying them into nets. The Pioneer uses a three pole configuration. The poles form a "V," and the net is strung across the mouth of the "V." Wires run from the poles which hold the net to the third pole. When the RPV flies into the net, the net is allowed to slip forward on the wires while the vehicle's energy dissipates. The Mastiff, which landed on the flight deck of the USS Tarawa (LHA 1), used a more conventional system with two pendant wires and a barrier net similar to an aircraft carrier's conventional emergency barricade nets. This method required precise control as the RPV flared to engage the hook. Obviously, this two pole method would be suitable only for ships with large flight decks. (Naval Sea Systems Command 1987)

Net recovery has the advantage of not having to carry recovery gear in the UAV (such as parachutes, parasails, or landing gear), not involving outside units in the recovery (other ships or helicopters), and avoiding water landing.

The disadvantages of net recovery are that it is most suitable for use aboard large surface ships; it is time-consuming to set up and take down the nets; and the vehicle is required to fly directly at the ship (risking collision and subsequent damage to the vehicle and ship).

Additionally, the ship is not a stable platform (dependent on sea-state) and it creates wind vortices which the vehicle may encounter during its vulnerable landing phase. Additional documented problems which the Navy has addressed included: software problems with the autoland system, engine failure, and electromagnetic interference (EMI). (Naval Sea Systems Command 1987)

As a final note, net recovery appears to be feasible only for relatively small, slow UAVs.

b. Parachute

A common method of recovery is by a parachute which either deploys when commanded by the controller or at a predetermined time or place. This has serious drawbacks for use at sea. The vehicle lands in the water, causing saltwater immersion of the RPV and risking saltwater contamination. If the vehicle fills with seawater, lifting it may cause structural damage. Furthermore, water landing requires that a boat, ship or helicopter recover the UAV. This can be extremely difficult in high sea-states, adverse weather, and darkness.

In wartime it could be dangerous for a ship to slow or stop to pick up a UAV (or to lower a boat to recover a UAV). Additionally, if a helicopter is used, it temporarily will be unavailable for its primary mission.

c. Parafoil

Similar to parachute recovery is parafoil recovery. Under this method, the UAV deploys a parafoil at the end of the mission, while the engine continues to produce power. In tests, using a 40 percent scale model of the Skyeye remotely piloted vehicle, Developmental Sciences officials reported parafoil recovery resulted in lower landing speeds and (implicitly) reduced landing shock to onboard equipment. ("Developmental Sciences Tests Parafoil" 1987, 92)

The slower approach speed reduces the probability of damage to the recovering ship and the UAV, but this method also has drawbacks. Carrying the recovery system increases the vehicle's weight or reduces its payload capacity; wind and ship speed changes complicate recovery; and a specialized guidance system is probably needed to direct the vehicle into the net. Removing the UAV from the net may be difficult, considering the number of shroud lines associated with parafoils. (Naval Sea Systems Command 1987)

Parafoil recovery is difficult at night and in periods of reduced visibility. Additionally, the system is probably best for recovering relatively small UAVs.

d. VTOL

VTOL offers the advantages discussed in the "launch" section of this chapter. VTOL UAVs allow the

greatest flexibility in deployment at sea; they can be designed to operate from a large number of ships because they require so little deck space for launch and recovery. This option is most attractive for short range UAVs.

VTOL types include remotely piloted helicopters and tilt rotor vehicles. The latter shares many of the capabilities of the former but operates at higher maximum speeds. Tilt rotor vehicles generally require more deck space for launch and recovery because of the size of the propellers.

e. Helicopter Midair Recovery

The concept of midair retrieval was developed to recover the film ejected from reconnaissance satellites. The same idea was used to recover Ryan model 147 RPVs in Southeast Asia beginning in 1966.

In Vietnam, the original problem recovering the RPVs was that they often sustained damage from landing in the rice paddies, the jungle, or the ocean off Da Nang. The solution was the MARS system; a helicopter equipped with a grappling hook was used to catch the UAV while it descended by parachute. Once hooked up, a mechanism freed the drone's main parachute to float clear. Then the vehicle was reeled in (after its speed stabilized), until it was stowed about 15 feet below the helicopter. This system allowed vehicles to be brought back and set down gently (Wagner 1982, 108-09)

Although the MARS recovery system required the dedicated use of a helicopter, it was a successful method of recovery. In extended operation in Southeast Asia, 2655 MARS 'catches' were made in 2745 attempts for a 96.7% success record. (Wagner 1982, 109)

f. Conventional

While theoretically possible, there seems to be little enthusiasm for the idea of landing UAVs on ships conventionally. As discussed above, the Mastiff RPV was landed on the USS Tarawa (LHA 1) in a way that is similar to conventional carrier landings. The disadvantages of this method are that it is necessary to erect a barrier along the safe parking lines to protect the aircraft parked on deck, and this method is only suitable for ships with large flight decks. (Naval Sea Systems Command 1987)

E. SENSOR TECHNOLOGY

Advances in technology have made possible UAV sensors that allow high-resolution imagery to be relayed in real or near real-time to the commander. The following is a summary of the sensors with which UAVs can be equipped.

1. Television

The obvious appeal of being able to observe the battlefield (or target) in real-time has made television the most commonly used UAV sensor for reconnaissance and surveillance: the Pioneer, Mastiff and Scout RPVs are but a few examples. Small and light-weight television cameras are

inexpensive and widely available. The Naval Air Development Center has operated a very small television camera (approximately 2 x 2 x 7 inch) from an RPV. A small television camera with a zoom lens is able to detect objects such as tanks on the battlefield at approximately 3-5 miles. (Coburn 1986, 34-35)

Although television offers size, weight and cost advantages, it suffers from the drawbacks that it is limited to day, visual meteorological conditions. It is restricted by the inability to image through haze, smoke, fog or clouds. (Coburn 1986, 35)

2. EO/IR Sensors

IR sensors have important advantages over television sensors: they are capable of imaging through haze, dust and certain fog conditions, and at night. Two common IR sensors are foward-looking IR (FLIR) and IR linescanners (IRLS).

Night IR imagery can yield significant intelligence when it is compared to daytime imagery of the same scene. IR sensors can provide information in addition to visual imagery because of the thermal contrast that hot objects such as tank engines present within a scene. (Coburn 1986, 35)

As computer technology lowers the cost and the size of imagery enhancement systems, the intelligence community should be able to use them to obtain high-resolution imagery from sea-based imagery platforms (either manned or unmanned).

> IR sensors are more readily adaptable to digital data processing, storage or transmission than conventional photographic systems; so these sensors are ideal for real-time data linking of reconnaissance, surveillance or targeting data to a ground station for analysis and/or tactical action. (Coburn 1986, 35)

Northrop has proposed its NV-144R to meet the Navy's requirement for an interim medium range UAV. The proposed sensor package includes an IR line scanner, the Honeywell D500. This sensor provides high-resolution imagery in day or night missions. It has a wide swath, allowing the vehicle to cover the target in only one pass. The vehicle would be able to store the imagery if it cannot be passed back to the operations center immediately. ("Northrop" 1987, 326-27)

3. Radar Sensors

To avoid the effects of weather and darkness, radar sensors can be used by UAVs. High resolution target detection and classification may be possible by using high frequencies such as X, K_u, K_a and millimeter wave frequencies. Millimeter wave radars have the advantages of high resolution, small component size and antenna aperture, but may be more affected by moisture or rain. (Coburn 1986, 36) One of the attractive characteristics of radar is that it allows the vehicle to image its target from a distance. Other imaging sensors, such as IR linescanners, require the vehicle to overfly or nearly overfly the target, increasing the probability that the UAV would be shot down.

IV. EMPLOYMENT OF UAVs AT SEA

Chapter Three outlined the strengths and weaknesses of UAV technologies. This chapter investigates how UAVs can collect imagery intelligence (IMINT) to satisfy requirements for reconnaissance in support of the fleet.

Considering the state of technology, UAVs cannot totally replace manned reconnaissance aircraft. There are situations where manned aircraft should be used. For instance, if the threat to aircraft is low, a manned aircraft may be an acceptable platform. If the target is at a great distance, a long-range manned aircraft (perhaps refueled in flight) may be required to collect intelligence. However, if the target is heavily defended, or if the loss or capture of an aircrew is unacceptable, the UAV would be a logical choice.

The trend in military affairs over the past century has been toward more technologically advanced weapons systems. Today long-range, highly accurate weapons are already in the inventory and more advanced weapons are planned. But with the capability to conduct strikes over long ranges comes the need for highly accurate and timely intelligence.

In modern naval warfare, the advantage goes to the side that is able to attack effectively first, and the key to attacking first is to have superior reconnaissance and

intelligence. Effective fusion of reconnaissance, surveillance, and intelligence is so important that it must receive the same emphasis as the delivery of firepower. (Hughes 1986, 34-39)

Highly accurate anti-ship and land-attack missiles, as well as strike aircraft capable of pinpoint bombing, are of little value unless the commander knows where the enemy is. (Hughes 1986, 39) Unmanned Air Vehicles (UAVs) are being developed to supplement the existing intelligence sources. The UAVs will be useful in those cases where current sources are too ambiguous, slow, dangerous to the crew, or take resources away from their primary duties.

In time of war it is almost certain that national imagery intelligence assets will be overburdened with tasking. The enemy undoubtedly will put great emphasis on disrúpting and interdicting the handful of intelligence-gathering assets and their associated command, control and communication (C^3) systems. It may be possible to prevent this potentially disastrous situation by deploying the tactical unmanned air vehicles now under development.

A. IN SUPPORT OF ANTI-SURFACE WARFARE

The long ranges of anti-ship missiles can be exploited only with timely and accurate intelligence. Organic aircraft such as LAMPS helicopters theoretically could provide some of this intelligence; however, the current

anti-air threat posed by modern surface ships virtually rules out the use of helicopters for conducting target classification and battle damage assessment. Over-the-horizon (OTH) targeting and classification are carried out before the attack, when a target force's air defense net is strongest. Battle damage assessment is carried out before the neutralization of the target has been confirmed. In either case, the use of manned aircraft, especially helicopters, would be dangerous.

In order to fully utilize the capabilities of long-range surface-to-surface missiles and strike aircraft, OTH targeting, classification, and BDA must be provided. UAVs can supplement or completely replace existing assets in carrying out these critical missions.

Anti-ship missiles are of little value unless the commander knows where the enemy is. If each side is armed with long-range missiles, what matters is the productive range--the range at which a decisive number of weapons may be expected to hit their targets (Hughes 1986, 39). UAVs may be used to increase the productive range of surface-to-surface missiles by improving OTH intelligence. UAVs would be most useful when other means of gathering the intelligence are too ambiguous, slow, or dangerous to the crew. Also, UAVs would free manned aircraft to carry out their primary missions.

BDA is one of the surface action group's greatest deficiencies since LAMPS helicopters almost certainly would not be used in a high-risk environment. A UAV such as the Navy's proposed medium range (MR) UAV system will fill this gap because of its 300 NM range, its high-resolution imaging payload, and its real-time data-link capability. But most importantly, the UAV will not risk the lives of any crewmen.

Table I

COMPARISON OF RECONNAISSANCE PLATFORMS

	MANNED AIRCRAFT	LAMPS	MR UAV
Crew Risk	Yes	Yes	No
Speed	Supersonic	Medium	High-subsonic
Personnel Cost	Very high	Very high	Medium
Detectability	High	High	Medium
Range	Long	Short	Medium
Airframe Cost	Very high	Very high	Medium

B. IN SUPPORT OF TACTICAL AIR STRIKES

Today's imaging satellites are technically capable of providing coverage of virtually any target on Earth. These sensors, however, are not under the control of the Officer in Tactical Command (OTC), and therefore may not be available in time to accomplish the mission at hand. This is further complicated by the fact that satellite coverage may be impossible at a specific time because of the position of the sensor, higher priority tasking, or because the target is obscured by weather.

The carrier battle group commander does control some imagery intelligence assets, such as the Grumman F-14A equipped with the Tactical Aerial Reconnaissance Pod System (TARPS), which was developed in the 1970s as an interim "fix," although it has ended up being thought of as a long-term solution. It is capable of conducting minimal stand-off reconnaissance but lacks a real-time capability.

The Navy plans to introduce a new system in the 1990s to replace TARPS: the Advanced Tactical Air Reconnaissance System (ATARS), to provide high-resolution, real-time imagery from as far away as 350 NM from the launch platform ("Operational" 1986, 48). The major elements of the ATARS program include the General Dynamics Tactical Air Reconnaissance System (TARS) and the Unmanned Air Reconnaissance System (UARS). The TARS, which is now in full-scale development, will be installed in Air Force/McDonnell Douglas RF-4Cs and in the MR UAVs; it may also be installed in some Navy and Marine Corp McDonnell Douglas F/A-18s. The TARS also includes a tactical ground station using modular technology developed under the Advanced Deployable Digital Imagery Support System (ADDISS) program. The unmanned portion of ATARS is a joint Navy and Air Force program, with the Navy as lead service for development of the MR platform and the Air Force developing the sensor package. (Weinberger 1987, 201)

The MR UAV, equipped with ATARS sensors, will provide high-resolution imagery in high-threat areas, thereby minimizing the need for manned aircraft. The ATARS sensor package will be costly when compared to film reconnaissance systems or TV sensors. It will, however, be able to deliver to the commander the same high-quality thermal-imaging and high-resolution optronic imagery as manned reconnaissance aircraft (Hewish 1987, 1198).

C. SPECIAL OPERATIONS

Unmanned reconnaissance vehicles offer several advantages in anti-terrorist operations. Most importantly, imagery can be obtained without risking a flight crew. We need to collect timely intelligence, but we do not want target groups to capture personnel in the process. Weather conditions can prevent satellite or high-altitude reconnaissance for days at a time. Also, the U.S. may wish to avoid the diplomatic and political complications associated with manned overflights. UAVs would be a lower profile method of gathering the essential imagery.

One of the lessons learned in the Navy operations in Lebanon, Libya, and the Persian Gulf is that today, Third World nations often are armed with modern air defenses. The manned reconnaissance aircraft may be able to avoid overflights altogether if ATARS medium range UAVs are available.

D. IN SUPPORT OF AMPHIBIOUS OPERATIONS

U.S. amphibious assault forces are capable of rapid deployment to distant trouble spots in support of the national interest. To accomplish this the Navy and Marine Corps work as a team, with the Navy providing sea lift as well as support at the location of the landing. As ATARS-equipped aircraft and UAVs enter the inventory in the 1990s, the commander of the amphibious assault will be able to see deep into the amphibious objective area, with great accuracy and in a timely manner.

With ATARS sensors, the Navy, Marine Corps and Air Force will be able to share imagery in real-time via the mobile Joint Services Imagery Processing System (JSIPS). JSIPS facilities will receive not only Navy, Marine Corps and Air Force UAV imagery in real-time, but ATARS imagery data-linked from Navy and Marine Corps F/A-18s and Air Force RF-4Cs. JSIPS will allow both shore- and sea-based units to receive real- and near real-time soft copy imagery products. According to Rear Admiral J.M. Seely of the Air Warfare Division in Naval Operations, "[JSIPS] will also allow reception of both national and strategic sensor products by the local commander." (Lucas 1987, 398)

Since ATARS is being developed jointly, the intelligence it provides will be compatible with the processing facilities of all three services. While a War-At-Sea scenario is not so dependent on joint operations

for success, the success of amphibious operations is heavily dependent on joint operations. ATARS and JSIPS are ideal for such operations because they allow the rapid exchange of imagery.

E. IN GENERAL WAR

In a general war, UAVs would relieve tactical aircraft of the most dangerous reconnaissance missions. If a future war is fought with only those weapons on hand, valuable aircraft and crews must not be risked unnecessarily. UAVs would give the commander the option of having a lower cost system for reconnaissance, while saving manned aircraft for missions for which they are optimized.

F. COST-EFFECTIVENESS

UAVs can be constructed to carry out many kinds of missions, but are UAVs a cost-effective platform for conducting reconnaissance? Although detailed cost-benefit analysis of specific UAVs is beyond the scope of this study, a review of the history of "Buffalo Hunter" missions flown over Southeast Asia between January 1969 and June 1973 does provide enough information to give a rough estimate. The AQM-34L model 147SC was the workhorse of the program, accounting for nearly half of the missions flown (see chapter 2). The "SC" flew low altitude photo-reconnaissance missions, primarily over North Vietnam. The record shows that the average vehicle flew 7.3 missions. (Wagner 1982, 99-100)

Using the record from the Vietnam UAVs as a guide, a rough estimate can be made with respect to the survivability of UAVs against a hostile air defense system. For purposes of comparison, assume that a UAV could be expected to fly seven combat missions. If the cost of the UAV is one million dollars, then the loss of UAV hardware (per mission) would be 143 thousand dollars.

If the cost of a single manned aircraft is set at twenty million dollars, a manned aircraft would have to fly 140 missions against the hostile targets to equal the UAV's costs due to lost hardware. Therefore, if we expect a manned aircraft to survive more than 140 reconnaissance, targeting, and BDA missions against hostile targets, then the cost of lost hardware would be lower for this hypothetical aircraft. If we expect the manned aircraft to average fewer missions before loss, then the UAV would be the more cost-effective platform.

This analysis is not intended to be a precise estimate of cost-effectiveness, but is presented for purposes of comparison only. It assumes the UAV could carry out the mission as well as the aircraft. It also ignores the differences in operating expenses, which would tend to be cheaper in the case of the UAVs. And it figures cost-effectiveness in terms of airframe and sensors costs only, ignoring such things as crew training.

Obviously, the higher the probability that the reconnaissance platform will be lost to enemy fire, or the greater the cost difference between the UAV and a manned aircraft, the more attractive the UAV appears.

Considering that the cost of the Tomahawk missile (BGM-109) is in excess of two million dollars each, and their loadout aboard ship is limited, it is easy to understand that real-time imagery of the target prior to launch and timely BDA would quickly become cost-effective in the eyes of the commander. Weapons employment and follow-up attack decisions require exact, current information about the prospective target. To maximize the probability that he will prevail in war at sea, the on-scene commander must have a superior intelligence system.

V. CONCLUSION

> The reason the enlightened prince and the wise general conquer the enemy whenever they move and their achievements surpass those of ordinary men is foreknowledge.
>
> Sun Tzu (Richelson 1985, 6)

Military commanders have long dreamed of being able to see their enemy over the next hill. Today, the commander does have access to systems which can provide such a peek at his enemy. The U.S. Navy OTC in a carrier battle group currently commands TARPS-equipped F-14As which are capable of gathering photographic intelligence on film. He may also ask to receive IMINT support from national sensors. Although each of these is quite capable, neither is without drawbacks.

Unmanned air vehicles are being developed that will fill the gaps in the current naval imagery collection system. These vehicles have three predominant advantages: they will relay the imagery to the tactical commander in real- or near real-time; they will do so without risking an expensive manned aircraft and its crew; and they will be operated under the immediate direction of the on-scene commander.

The key questions are: can UAVs collect IMINT? Can they operate at sea? Is there a need for the intelligence they would collect? And are they cost-effective?

Unmanned air vehicles can gather imagery. UAVs equipped with television cameras or forward looking infrared (FLIR) sensors have already been deployed, both in the U.S. and abroad. The U.S. Navy began flying the television-equipped Pioneer RPV from the USS Iowa (BB 61) in 1986. Since then, in one test, sixteen-inch naval gunfire was controlled for over two hours using the Pioneer's television camera and data-link.

Better resolution is available for UAV sensors: infrared (IR) line scanners are now available, and digital EO sensors are being developed under the Advanced Tactical Air Reconnaissance System (ATARS). ATARS' sensors will offer the OTC high-resolution IMINT in real-time. The sensors will be deployed on both manned reconnaissance aircraft and medium-range UAVs, thus offering the tactical commander the option of using either manned or unmanned reconnaissance platforms.

UAVs have operated at sea. In addition to the Pioneer short-range remotely piloted vehicles deployed with the USS Iowa, during the Vietnam War, the Navy launched and recovered Ryan model 147SKs from the USS Ranger (CV-61) in a research and development (R&D) evaluation of the medium-range photo-reconnaissance UAV. The "Belfry Express" missions, which were conducted between November 1969 and June 1970, produced reconnaissance photographs useful for air order of battle and targeting purposes. Reportedly

their quality was superior to that collected by USS Ranger's manned reconnaissance squadron because the RPVs flew under the overcast during monsoon weather to provide high quality low altitude photography. Due to the R&D nature of the project, the RPVs suffered from reliability problems. When they did operate properly they provided photography that was unavailable from other sources. (Channell 1988) The cameras carried by the AQM-34L (model 147SC), which was similar to the model 147SK, achieved 3-5 inch resolution on low altitude missions over Vietnam. (Wagner 1982, 195)

Even though UAVs can operate at sea, and gather IMINT, the question remains: does the Navy require the intelligence they can gather? First, recall that the trend in modern war at sea has been toward long-range, very accurate and very expensive missiles. Because of this, the tactical commander needs timely intelligence. To fully utilize such missiles, he requires OTH targeting, classification, and BDA. Although manned reconnaissance aircraft can be used to carry out these missions, the threat of air defenses is increasing. Additionally, surface action groups are equipped only with LAMPS helicopters which are even more vulnerable to those defenses.

Tactical air strikes also require imagery intelligence support. The F-14A TARPS, organic to the carrier battle group, is a valuable asset. TARPS can collect the necessary

photographs, but UAVs could gather the same intelligence in real-time, and without risking the aircraft and crew.

Imagery intelligence support could also come from national reconnaissance systems, such as satellites, Lockheed SR-71s or Lockheed TR-1s. These assets are extremely capable, but they are not subordinate to the on-scene commander, and therefore may not be able to provide him intelligence to meet the critical real-time requirements of tactical operations. UAVs deployed aboard the battle group can do just that. Moreover, they may be capable of flying below cloud cover or of loitering for an extended time to image targets and relay the intelligence to the commander as it is imaged.

Are UAVs a cost-effective platform for collecting imagery intelligence? The cost-effectiveness of UAVs is impossible to precisely gauge because one of their chief advantages is that they save lives; yet it is clear that as missiles such as Tomahawk and as tactical strike and reconnaissance aircraft become more costly, the attractiveness of UAVs becomes incontrovertible.

Apart from the humanitarian aspect, the political advantage of gathering IMINT without risking the death or capture of American servicemen looms large if military actions similar to the strikes on Libya or Lebanon need to be carried out in the future. In situations where American national leaders insist on an absolutely minimal risk of

aircrew death or capture, UAVs will be extremely valuable. A precise appraisal of UAV value is practically impossible because it requires the quantification of intangibles such as the cost of a flightcrew's life, the impact on national prestige of a failed or errant attack, and the limitations on foreign policy imposed by the prospect or consequences of captured American servicemen.

The deployment of UAVs capable of providing high-resolution IMINT in real-time will not come without cost. But in a world of finite resources, UAVs will also help conserve expensive tactical aircraft which would otherwise be ordered to overfly heavily defended targets. Additionally, expensive surface-to-surface missiles will be conserved because of the UAV's ability to conduct targeting, classification and bomb damage assessment.

While UAVs are not a panacea, they are capable of filling gaps in the existing IMINT system. The fact that they cost a small fraction of the price of a tactical aircraft and that they do not endanger the lives of crewmen means that they are ideal for high-risk missions.

This thesis can only serve as a starting point in the debate over how UAVs can be used to improve the Navy's IMINT system. Even as naval civilian and uniformed leaders must make difficult budgetary decisions, we should carefully reflect on our national military strategy and the trends in modern warfare.

The latter seem to be toward more accurate weapons systems and a faster pace of war. Such weapons will require an extremely effective intelligence system. UAVs can assist the tactical commander by flying into the most heavily defended areas and reporting the situation in real- or near real-time. If future wars are fought at a fast pace, with very high rates of weapons depletion, ships may not have time to reload their magazines, and commanders will want to make every round count. Furthermore, as the costs of weapons rise along with their increased capability, it will become even more important to increase the effectiveness of each strike. In a fast-paced war at sea, with both sides armed with long-range missiles, it will be important not only to strike first, thereby preventing the enemy from firing his weapons, but to follow up strikes with reconnaissance so that the OTC can make an informed decision about additional strikes.

One way of accomplishing this is to improve the intelligence system that provides the classification, targeting and battle-damage-assessment to the OTC. If strike weapons are costly and limited in number, the pressure will be on the intelligence system to assist the tactical commander in deciding how best to employ those finite assets. UAVs can provide this intelligence.

It has been shown that UAVs already have been used in combat to conduct missions that were too dangerous or that

could not be carried out by manned aircraft. Currently, the Navy, Air Force and Marine Corps are developing UAVs which will be able to fly as far as 350 NM from the launch point and data-link imagery to the OTC in real- or near-real time. Furthermore, this imagery will be comparable in quality to that gathered by manned reconnaissance platforms.

This thesis concludes that UAVs should not replace manned reconnaissance platforms, but they are most cost-effective when the threat to the aircraft is high. UAVs have not enjoyed consistant funding. In time of war, they have been in demand; but in peacetime, when their specialized, high-risk missions are not conducted, funding has disappeared. However, by continuing to fund UAVs in peacetime, and by deploying them as soon as possible, we will be prepared to save lives while putting ordnance on target from the start of any future war.

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